The Effect of Laser Energy and Nitrogen Flow in Solder Joints Properties of Head Gimbal Assembly

Kittimeth Wattananaphakasem, Ubolrat Wangrakdiskul, Jakawat Deeying

Abstract: ***The objective of this research is to study the effect of laser energy and Nitrogen flow on the solder joints of the Head Gimbal Assembly (HGA). The soldering of the HGA components isn't the same as general semiconductors. Since the soldering figure perpendicular to each other so that, it was used the laser solder jet bonding system. The solder jet bonding system uses a solder ball consisting of Sn-2.0Ag-0.7Cu (SAC207) is used for connection of the HGA pad made from a Cu trace coated with Au. The growth of intermetallic compounds (IMCs) and shear strength will be analyzed to investigate the effects of laser energy and Nitrogen flow on solder joint reliability. In this research, laser energy levels since 2, 2.5, 3, 3.5, 4, and 4.5 mJ and keep the Nitrogen flow value at 90 mbar. As for the Nitrogen flow effect analysis, the Nitrogen flow level was used at 80, 100, 120, and 140 mbar and keep the laser energy value 3.5 mJ. The results of the study show that the increased levels of laser energy can inhibit the growth of intermetallic compounds as well as the $AuSn_4$ phase that can present benefit to solder joints with results showing within the shear strength to increase significantly. The increase in Nitrogen flow levels has the same effect as the increase in laser energy levels, which can decreases the growth of intermetallic compounds and $AuSn_4$ phase also including increased shear strength. The difference between laser energy and Nitrogen flow increasing shows the level of laser energy can clearly distinct the effect on each level. But the increase in Nitrogen flow level is statistically insignificant from each level.***

Keywords: Intermetallic compound, Laser solder jet bonding, SAC solder, solder joints

I. INTRODUCTION

In the past, the production industries have manufactured a Micro-electronics that Sn-Pb solder has been used in production due to Sn-Pb solder has the best qualification such as has good electrical conductivity and a low melting point. However, the disadvantages of Sn-Pb solder is Pb toxicity that affects the environment and humans. It has caused World-Wide rules and regulations, environmental regulations such as Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous (RoHS) prohibiting the use of Pb in all electronic devices which have been identified [1]. In a decade, the wide development Lead-Free solder for similar qualification Sn-Pb and proper for another electronics were discussed in [2]-[4]. At present, there are many types of Lead-Free solder. SAC solder is one of the most popular and accepted, Lead-Free solders due to its excellent mechanical and wetting ability

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Kittimeth Wattananaphakasem*, Production Engineering Department, Faculty of Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand. Email: eark.bakery@gmail.com

Ubolrat Wangrakdiskul, Production Engineering Department, Faculty of Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand. Email: ubolrat.w@eng.kmutnb.ac.th

Jakawat Deeying, Western Digital Thailand Co.ltd Bang Pa-in Industrial Estate, Khlongjig, Bang Pa-in, Phra Nakhon Si Ayutthaya, Thailand. Email: Jakawat.deeying@wdc.com

close to Sn-Pb solder and can be used to replace Sn-Pb solder were presented by [5]-[7]. SAC solder has the main component is Sn-Ag-Cu. In the production of SAC solder, there is no fixed rule of mixing Sn-Ag-Cu or other elements that help increase the efficiency of solder. In the soldering process, the solder was melted and integrated into the substrate, resulting in a thin layer near the substrate called intermetallic compound (IMC). Understanding the mechanism of the formation of the IMC is very important in analyzing solder joint quality. The microstructure and the growth rate of the IMC depends on the components in the solder and the substrate used has also been reported [8]-[9]. Microstructure and growth of the IMC directly affects the reliability of solder joints. The growth of the IMC and the occurrence of kirkendall voids will reduce the mechanical properties of the solder joints and ultimately reduce the reliability of solder joints [10]-[12]. The addition of nanoparticles to the solder or substrate affected the microstructure characteristics and the growth rate of IMC for example, The effect of adding different amounts of diamond nanoparticles (0.5, 1.5 and 2.5 wt.%) to SAC305 after reflow soldering was found to slightly reduce the melting point of SAC305. But adding nanoparticles from diamond can significantly reduce the thickness of IMC. The addition of diamond nanoparticles at 0.5 wt. % it has the best result, giving SAC305 an additional 77.5% hardness as proposed by [14]. Li Hui [15] have reported adding rare element Y to SAC305 has the same effect as rare element Ce and La, which can significantly improve the properties of SAC305. Such as wettability and mechanical strength adding rare earth Y to SAC305 should be between 0.05-0.25 wt.%. Kittichai Fakpan and Rungsinee Canyook [16] also found that if adding Sb or Zn in the amount of 1.0, 2.0, and 3.0 wt% to SAC305, it can reduce the occurrence of dendritic β-Sn phase significantly. Resulting in increased tensile strength and yield's strength. The potential of corrosion was increased as the amount of Sb added to SAC305. But for Zn, there was a small change when adding Zn to SAC305. Another important factor was the heat used to melt the solder as well as the cooling process. The solder also affects the microstructure and the growth rate of IMC [17], [18]. In the experiment about comparing the strength of the solder joints that have been reflowed by laser and the reflow process by infrared were presented by [19]. The results of the research show that the laser energy and the heat duration of the laser affected the microstructure of intermetallic compound (IMC). WANG, Jian-xin, et al. [20] studied the soldering process using SAC305 on Au / Ni / Cu pad.

The results show that the laser energy will provide a shear test value that is 70% higher than using reflow IR. Park, Yong-Sung, et al. [21] have investigated effects of fine size lead-free solder ball on the interfacial reactions and joint reliability by using SAC105 as a solder, it was found that using a smaller solder ball would result in changes in solder joint properties such as interfacial reactions, mechanical properties and a decrease in solder ball size resulting in the thickness of IMC to increase. In this study, the laser soldering process was used for fluxless Sn-2.0Ag-0.7Cu solder balls. Because the components of the Head Gimbal Assembly (HGA) to be soldered are perpendicular and the HGA's pad being very small requires specialized SJB equipment. Therefore, the laser soldering technique is called a laser Solder Jet Bonding system (SJB). The difference of the normal laser soldering is a process laser solder jet bonding system and is not applicable to this micro process. For HGA production the solder ball is melted with laser energy within the capillary. After that, Nitrogen gas expels the melted solder ball from the capillary to join the two pads electrically between as shown in Figure 1. In addition, nitrogen gas helps to cool the solder joints and further prevents oxidation of the solder joints during cooling. The objective of this research is to study the effect of laser energy and nitrogen flow of soldering by using a technique laser solder jet bonding system that affected the solder joint properties in HGA assembly. In this study, SEM & EDX was used to analyze the IMC layer microstructure of the solder joints and to measure the thickness of the IMC layer for the reliability of solder joints. Also, use of shear strength testing to analyze the reliability of the solder joints.

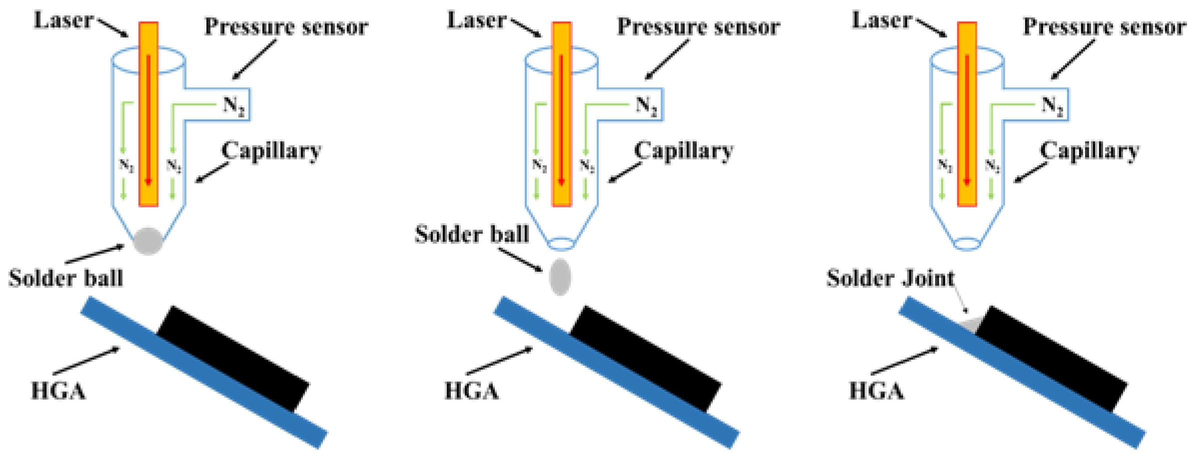

Fig. 1. Laser solder jet bonding system

II. EXPERIMENT AND METHODOLOGY

In this research, there are two groups for divided. The following are the study of the effect of laser energy and nitrogen flow. In the soldering was used the SJB system proceeds through the Laser solder jetting machine as shown in Figure 2. The laser solder jet bonding system process uses a fiber laser to melt the solder. The laser output wavelength is 1070 + /- 10 nm. The laser has a diameter of 50 µm. The HGA pads are made of Cu trace that is coated with Au. The solder ball used in the connection between pads has a diameter of 55 µm.

Fig. 2. Laser solder jetting machine

The study of the Laser energy effect, will adjust the Laser energy level and the Nitrogen flow value as shown in Table I. However, if the laser energy is less than 2 mJ. The capacity wettability of solder is reduced, resulting in the solder flow not properly covering the full HGA pads as shown in Figure 3. Likewise, if using laser energy higher than 4.5 mJ, it will cause the pad to burn as shown in Figure 4.

Table I: design levels laser energy used in the experiment effect of laser energy

Level of laser energy (mJ)	Nitrogen flow (mbar)
2	90
2.5	90
3	90
3.5	90
4	90
4.5	90

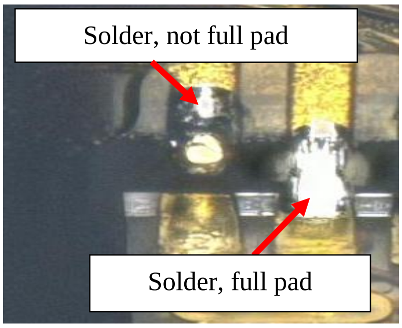

Fig. 3. Solder, not full flow pad due to use laser energy too low

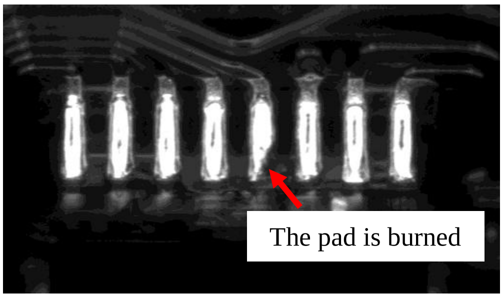

Fig. 4. Pad burns because laser energy is too high

In the education of the Nitrogen flow effect, different levels of Nitrogen flow will be adjusted. By defining the values of the laser energy as in Table II. Using a Nitrogen flow below 80 mbar, the solder ball will stick to the capillary area. As a result of the Nitrogen flow not having enough energy to push the solder ball away from the capillary tip. Moreover, if using a nitrogen flow greater than 140 mbar, it will make the direction of the solder ball drip on the pads missing the assigned target.

Table II: design levels Nitrogen flow used in the experiment effect of Nitrogen flow

Level of Nitrogen flow (mbar)	laser energy (mJ)
80	3.5
100	3.5
120	3.5
140	3.5

In the analysis of the shear strength of solder joints and proceeding through the computer-controlled electronic shear test gauge. In shear testing, the load resolution is 0.001 N and the sheer speed is 200 µm/min, as shown in Figure 5. The shear testing method uses the push head of the force gauge to push the parts of HGA assembly apart to break the solder joints and measure the shear force as shown in Figure 6.

As described earlier, the analysis IMC layer microstructure of solder joints is used via SEM & EDX to analyze. Preparation of solder joints in HGA cross-sectional solder joints. Because solder joints are very small and brittle, therefore cross-sectional solder joints using the focused ion beam (FIB) method are shown in Figure 7.

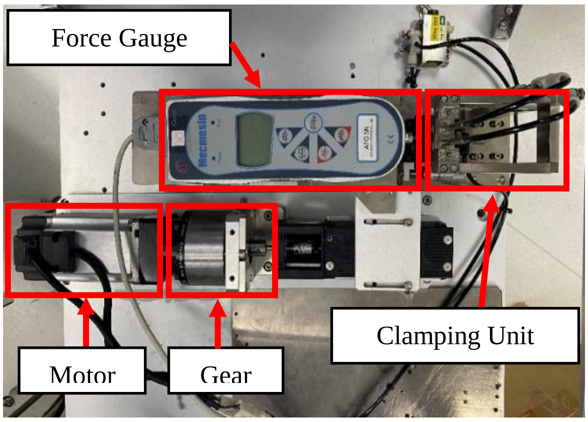

Fig. 5. Electronic shear testing machine controlled by a computer system

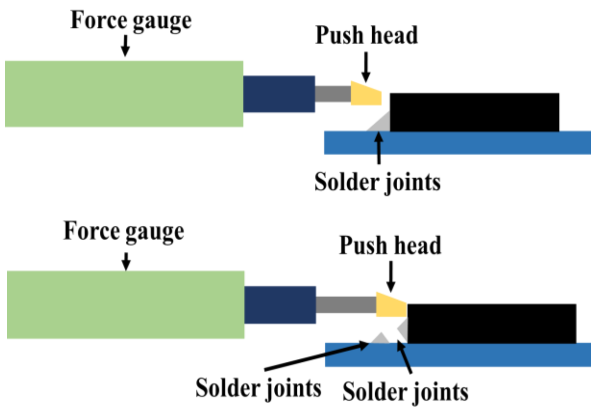

Fig. 6. Methods of testing the shear strength of solder joints in HGA

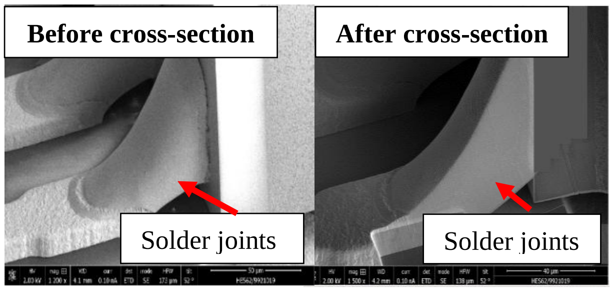

Fig. 7. The cross-sectional view of solder joints in HGA

III. RESULTS AND DISCUSSION

A. The effect of laser energy in solder joints

Figure 8, 9 and Table III show the microstructures IMC layers and thickness of IMC layer between the solder alloy and Cu substrate coated with Au. The result of the laser energy effect in the laser solder jet bonding system mostly found the spread of AuSn, $AuSn_2$ and $AuSn_4$ phase in the IMC layer. $AuSn_4$ phase has the highest growth rate. $AuSn_4$ is considered to be a very fragile period and is also a major cause of damage to solder joints. It is known that solder joints with less $AuSn_4$ have good quality and high reliability [22].

$AuSn_4$ has needle-like lamellar structures, but morphologies may vary due to the amount of Au or the melting temperature, as well as the cooling procedures of solder joints [23], [24]. The microstructural observation shows that the increase in laser energy at each level results in a reduction in the thickness of the IMC layer. The reduction in thickness of the IMC layer is a result of $AuSn_4$ decreases when laser energy levels are increasing and in addition to shear strength as illustrated in Table IV and Figure 10. It also shows that increasing laser energy levels can increase shear strength. Which corresponds to Figure 8, 9 and Table III. When the thickness of the IMC layer decreases, the shear strength values will be higher.

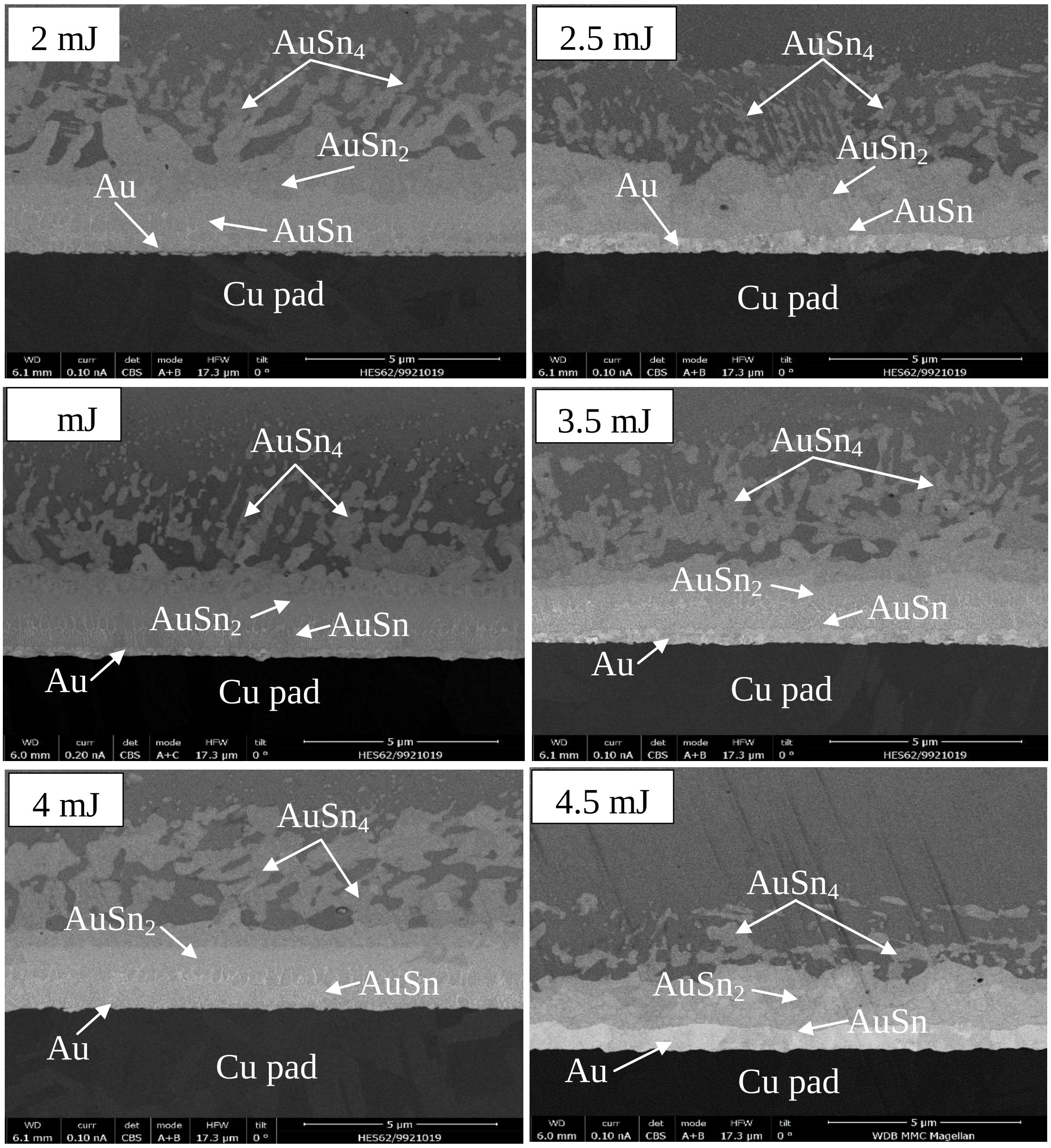

Fig. 8. The IMC of solder joints in the study of the effect of laser energy

Table III: The thickness of IMC layer in the study of the effect of laser energy

Level of laser energy (mJ)	Thickness of IMC layer (µm)
2	7.241
2.5	6.822
3	6.561
3.5	6.374
4	6.049
4.5	5.545

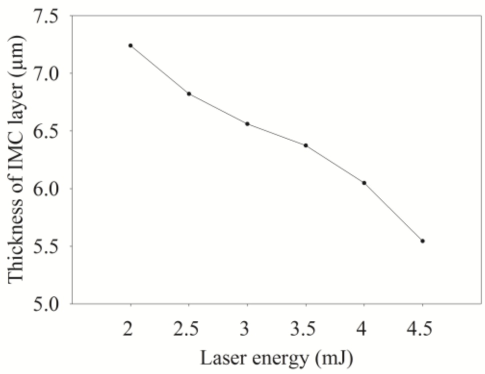

Fig. 9. The thickness of IMC layer in the study of the effect of laser energy

Table IV: Shear strength in this research of the effect of laser energy

Level of laser energy (mJ)	Shear strength (MPa)
2	31.244
2.5	32.623
3	33.457
3.5	34.253
4	35.067
4.5	35.729

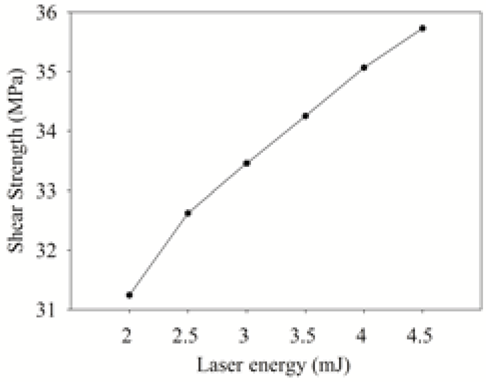

Fig. 10. Shear strength in this research of the effect of laser energy

B. The effect of Nitrogen flow in solder joints

In Figure 11, 12 and Table V, SEM images show the microstructure IMC layer and the IMC layer thickness measurement results of the Nitrogen flow study similar to the study of the effect of laser energy and found the diffusion of AuSn, $AuSn_2$, $AuSn_4$ and $AuSn_4$ still has the most diffusion. The increase in the Nitrogen flow level caused the thickness of the IMC layer to be slightly reduced, as well as the $AuSn_4$ growth also slightly decreased. When compared to the results of shear strength are show in Table VI and Figure 13, it is shown that the shear strength is high when the level of Nitrogen flow corresponds to the slightly reduced IMC layer thickness

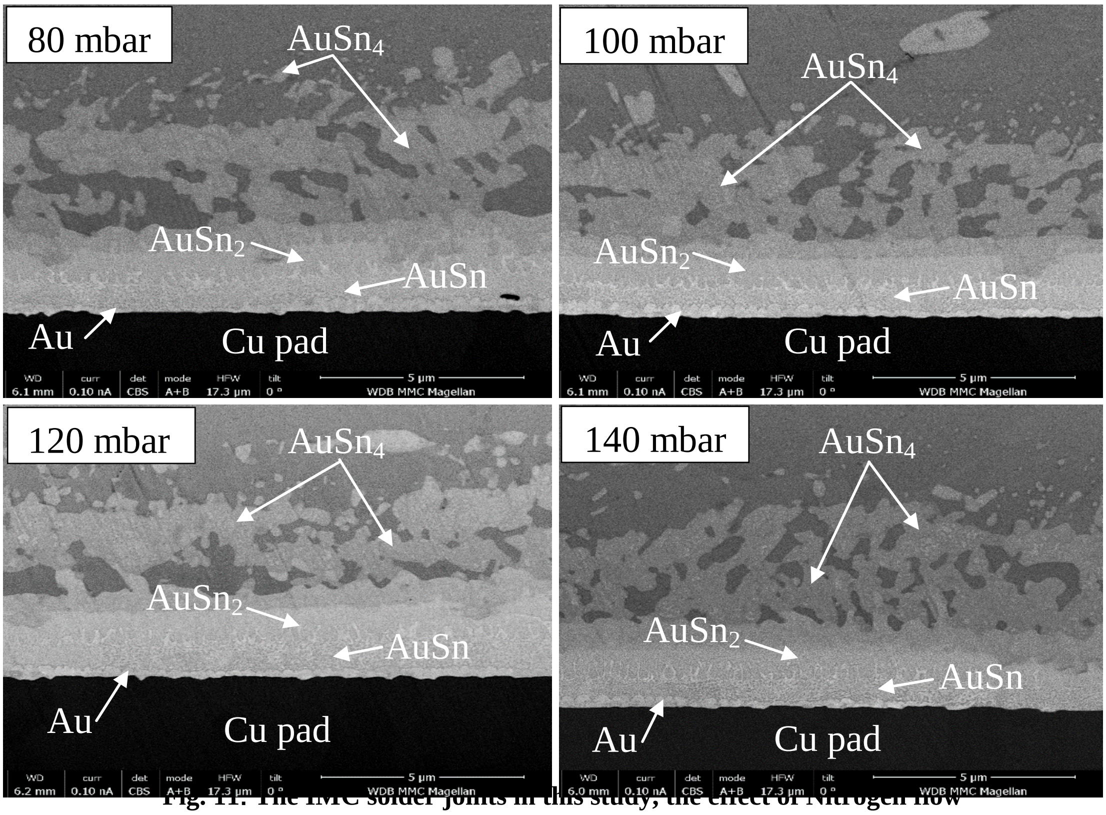

Fig. 11. The IMC solder joints in this study, the effect of Nitrogen flow

Table VI: The thickness of IMC layer that is the effect of Nitrogen flow

Level of Nitrogen flow (mbar)	Thickness of IMC layer (µm)
80	6.395
100	6.341
120	6.279
140	6.206

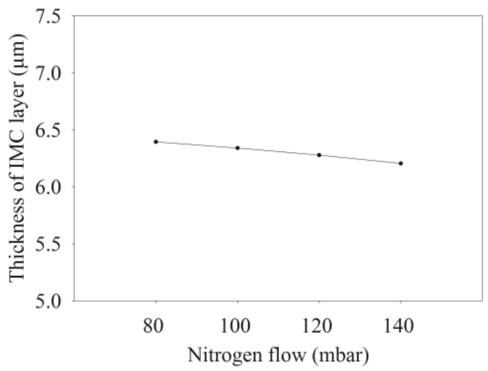

Fig. 12. The thickness of IMC layer that is the effect of Nitrogen flow

Table VII: Shear strength is the effect of Nitrogen flow

Level of Nitrogen flow (mbar)	Shear strength (MPa)
80	34.179
100	34.301
120	34.417
140	34.507

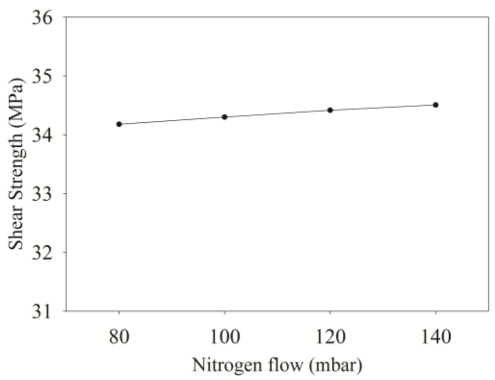

Fig. 13. Shear strength is the effect of Nitrogen flow

IV. CONCLUSION

This study has an objective to find the effect of laser energy and Nitrogen flow affects to the solder joints in an HGA assembly. Using the technique called laser solder jet bonding system which is summarized in the study as follows.

1. Increasing the laser energy level can reduce the growth of IMC layer. In addition, $AuSn_4$ phase also decreased, resulting highly increased shear strength of the solder joints.

2. The increase in Nitrogen flow level can inhibit the growth of IMC layer and $AuSn_4$ phase. Also the shear strength of solder joints increases as well as the level of laser energy.

3. When comparing the laser energy and the Nitrogen flow it is found the increase of the laser energy will produce significant changes in both the growth of the IMC layer and the reduced $AuSn_4$ phase. This results in the shear strength value of the solder joints is higher. The increase in the Nitrogen flow level shows changes in each level that are not considered viable at this time.

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AUTHORS PROFILE

Kittimeth Wattananaphakasem graduated in industrial engineering from Rajamangala University of Technology Suvarnabhumi in 2016. I'm interested in materials science. Currently studied a Master's degree at King Mongkut's University of Technology North Bangkok. Department of Production Engineering and an intern at Western Digital Thailand Co.ltd.

Dr. Ubolrat Wangrakdiskul works as Assistant Professor in the Department of Production Engineering at King Mongkut's University of Technology North Bangkok and there are many academic achievements in materials science both national and international level. Graduated with a PhD in Production Engineering from King Mongkut's University of Technology North Bangkok.

Dr. Jakawat Deeying works as Technologist at Western Digital Thailand Co.ltd. An expert and have academic achievements on DOE. Graduated with a PhD in Industrial Engineering from King Mongkut's University of Technology North Bangkok.